A REVIEW OF BENCHMARK PERFORMANCE IN PLATE MILL PROCESS CONTROL[1]

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Abstract

The first decade of the 21st Century has seen an explosion in the number of steel plate mills around the world. Significant increases in equipment power, resulting in wider process windows, coupled with through-process modelling of the temperature strain path and microstructural development have been the most obvious and discussed advances. This paper aims to address these recent advances. Just one example of modern technology is SmartCrown® combined with profile and flatness control. This has lead to increased plant throughput and to achieving the target profile more accurately with good flatness of the finished plate. Increased computer power has allowed for more detailed and higher quality process modelling. In addition, introduction of multi-point setup leads to higher resolution: through multi-point setup the complete plate behaviour becomes transparent and process parameters can be driven to a limit. The consequence is improved accuracy of the predictions for temperature, torque, load and several other key rolling parameters, improving performance, as well as permitting complex taper (longitudinally profiled) rolling for weight saving specialist applications. This paper includes comparative results demonstrating the improved performances that can be achieved with these key technologies.

Keywords: Plate mill; Profile control; Taper rolling.

AVALIAÇÃO DE PERFORMANCE NO PROCESSO DE CONTROLE DE LAMINADORES DE CHAPA GROSSA

Resumo

Na primeira decada do novo século notou-se um aumento significativo de laminadores de chapa grossa. Aumento em potencia, abrindo a abrangência de processo, combinado com modelos de processo de temperatura e de desenvolvimento micro-estrutural foram os avanços mais obvious. Este trabalho trata destes advancos onde um exemplo e a technologia de Smart Crown® combinado com controle de perfil e de planicidade na chapa final. Computadores mais avançados permitem estas tarefas de modelamento de processos avançados. Aditional, a introdução de setup multi-point permitiu uma resolução maior: com esta tecnologia o comportamento da chapa se virou transparente e os parâmetros se aproximaram aos limites. A consequencia foi a predição de temperatura, torque, forca de laminação e outros parâmetros chaves, melhorando performance, e permitindo geometrias complexas (taper - perfil longitudinal) para aplicações especiais. Este trabalho inclui resultados comparativos demonstrando a performance alcançada com esta tecnologia.

Palavras-chave: Laminador de chapa grossa; Controle de perfil; Laminação de taper.

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[1] *Technical contribution to the 48th Rolling Seminar – Processes, Rolled and Coated Products, October, 24th-27th, 2011, Santos, SP, Brazil*

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1 INTRODUCTION

Modern plate mills are generally benchmarked by their ability to produce two quite dissimilar products: Thin gauge e.g. 6 mm ship plate with minimum yield strengths typically ranging from 235 MPa to 355 MPa, and pipeline steels with thicknesses and minimum yield strengths typically ranging form 12 mm to 40 mm and 360 MPa to 550 MPa respectively. Thin ship plate is produced using an as-rolled (AR) schedule while pipeline steels are produced using thermo-mechanical controlled rolled with accelerated cooling (TMCP).(1) Additionally there is the requirement of future-proofing. Perhaps the best example of this is taper or longitudinally profiled (LP) plates, which have weight saving advantages, but have not been widely adopted by steel plate users.

The limiting factor for rolling thin material is achieving the target plate crown (absolute profile) whilst maintaining plate flatness at acceptable levels and working in a practical temperature range, above the transformation temperature, which itself introduces a limit, essentially on the maximum number of passes that can be used. Flatness is controlled by limiting the relative profile change within buckling limits.(2) As the plate becomes thinner the tolerable error becomes smaller, presenting the challenge of meeting both the target plate crown and producing flat plate.

For TMCP pipeline steels there is the added complication of including a hold to allow the plate to cool below the recrystallisation stop temperature. This has obvious influences on throughput, but there are ways to get round this with advanced multi-piece rolling and dynamic scheduling systems.(3) Here, due to the relatively low finish rolling temperatures we have very high rolling loads and greater variance in temperature through thickness and along the plate length. The TMCP process, particularly for products with a high hold ratio, which is a requirement for good low temperature toughness, imposes a smaller process widow. This can only be exploited by high power mills with good control systems.(4,5) Again, restraints are imposed, providing challenges of achieving the target plate crown and flatness at the thinner end of the pipeline steel product mix.

The backbone to accurately achieving the target crown and maintaining a flat plate is SmartCrown® with profile & flatness control (PFC). However, this is not possible to fully exploit without driving processing parameters to the limit, which is made possible through the use of a multi-point setup process controller, which has the added benefit of opening up a world of possibilities for the production of LP plates. The aim of this paper is to demonstrate recent advances in performance achieved with the use of SmartCrown, with multi-point setups for thin gauge, pipeline steels and LP plates.

2 SMARTCROWN® WITH PROFILE &FLATNESS CONTROL

2.1 Basic Description

The system of using bottle-shaped rolls with a ‘3rd order roll contour’ is a well-known and proven technology, which is in operation in numerous hot and cold rolling mills throughout the world. Siemens VAI’s latest development in the field of flatness control is a work roll contour called SmartCrown®, which offers significant advantages in terms of higher order profile and flatness control compared to the ‘3rd order roll contour’ technology. The basic principle of SmartCrown® and the ‘3rd order roll contour’ technology is very similar. Both systems utilize lateral shifting of the work rolls to adjust the loaded roll gap contour to match the relative crown of the ingoing strip, as illustrated in Figure 1.

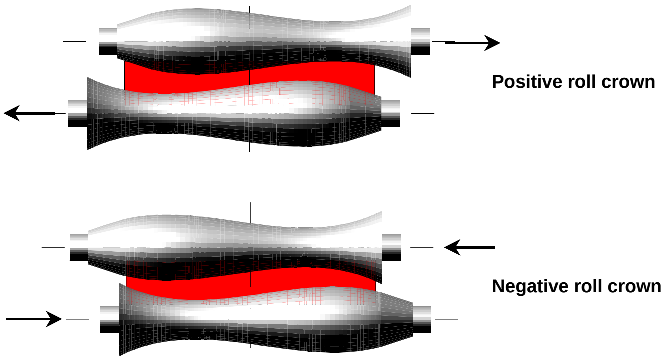
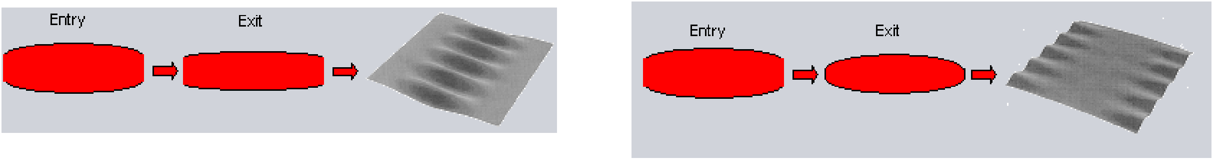


Figure 1. Demonstration of Roll Crown Positioning.

Whilst the basic principle is the same, SmartCrown® technology uses a different roll profile compared to the '3rd order roll contour' in order to optimise the flatness of the strip. The SmartCrown® roll contour can be described as a sum of a sinusoidal and a linear function (SMART = Sine Contour, Mathematically Adjusted and Reshaped by Tilting).(6)

When calculating the rolling schedule for a plate we need to determine the target plate crown as a function of the thickness for each pass (relative profile). Perfect flatness can be achieved if the relative profile is the same for every pass (relative profile is simply the actual crown thickness). If the relative crown on the exit side is lower than on the entry side then the middle part will undergo a larger reduction and become longer than the edges. Consequently centre buckles will be produced. These two main defects are illustrated in Figure 2.



Rel. Entry Crown > Rel. Exit Crown → Centre Buckle

Rel. Entry Crown < Rel. Exit Crown → Edge Waves

Figure 2. Development of centre-buckle & wavy edge flatness defects.

However, in practice, it is not necessary to have exactly the same relative crown for the entry and exit of each pass. The plate can tolerate a certain degree of crown change without producing bad flatness, particularly when it is thick.

PFC takes care of this. With highly sophisticated process models (Figure 3) in combination with an SQP optimisation algorithm proven in numerous industrial applications. The standard criterion for determining the allowable crown change is the Shohet & Townsend criterion, with the equation determining the limits shown below.(2)

$$-80\left(\frac{h_o}{w}\right)^y < \left(\frac{C_i}{h_i}-\frac{C_o}{h_o}\right) < 40\left(\frac{h_o}{w}\right)^y$$

Where:

- W is the plate width;
- hi is the entry thickness;
- h0 is the exit thickness;
- Ci is the entry crown;
- Co is the exit crown;
- y = 2 (Shohet & Townsend);
- y = 1.86 (Somerfield).

If the change in relative crown is within the limits of the criterion then the plate will be flat, but if the change in relative crown is greater than these limits then either wavy edges (-ve change) or centre buckle (+ve change) will be produced. So simply, by being able to change the roll gap profile SmartCrown® allows the required relative profile to be achieved over a range of loads. Figure 4 shows the PFC model calculated limits and target relative profile change to achieve a final plate crown (green line) of 60 μm for the finishing passes of a 6 mm thick plate without violating the buckling limits.

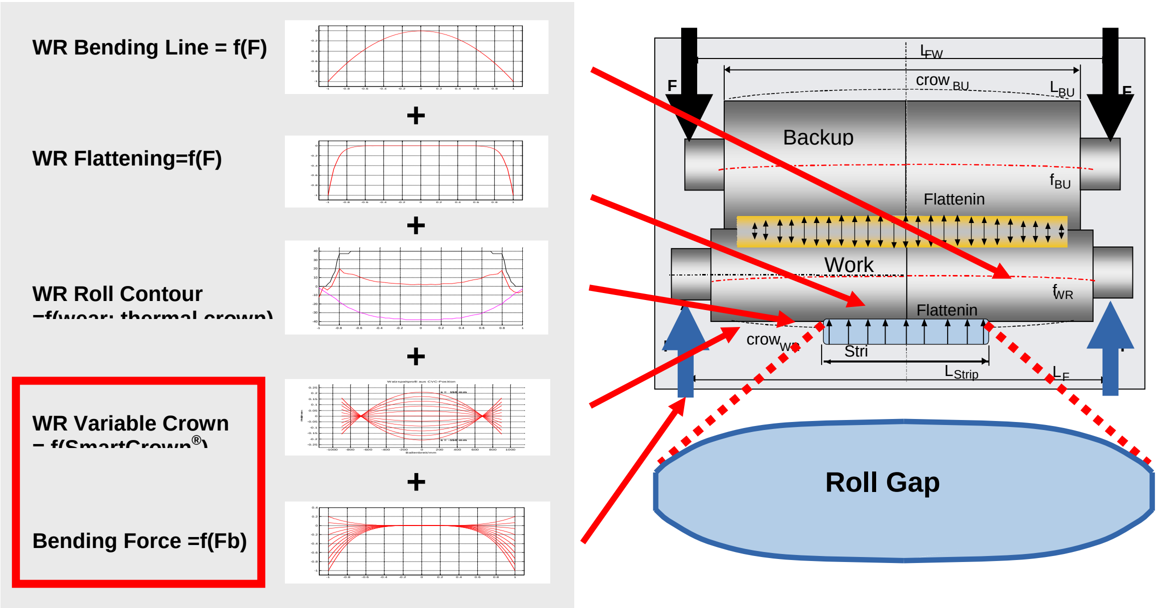


Figure 3. PFC model components.

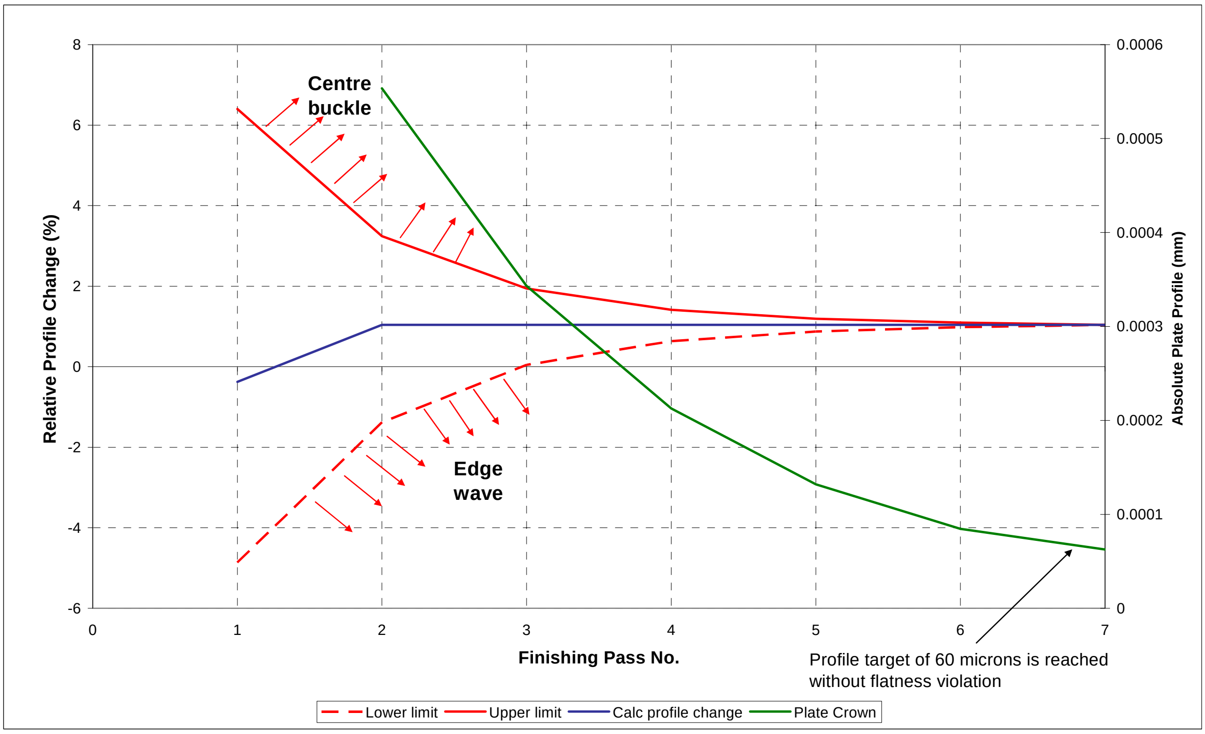


Figure 4. PFC model output for finishing passes for a 6mm plate with a target crown of 60 µm.

2.2 Recent Developments & Performance

Recently SmartCrown® has been pushed further than before. In wide plate mills, twice the previously used crown range has been applied since the first application to a plate mill.(7) This has resulted in even more aggressive rolling schedules to be used, applying the full shifting range over a rolling campaign. Figure 5 shows a comparison between a rolling schedule for a 6 mm x 3.000 mm plate with and without SmartCrown® in use. It can be seen that the schedule with SmartCrown is able to take higher reductions in the finishing passes, rolling the schedule in 9 passes, compared to 12 without SmartCrown®. There are obvious throughput benefits, additionally the pate is finished at a higher temperature, making it easier to roll and opening up the option of rolling wider products which would require additional passes. Figure 6 shows a picture of a 6 mm x 3.100 mm plate rolled on a 4.3 m wide plate mill equipped with SmartCrown®.

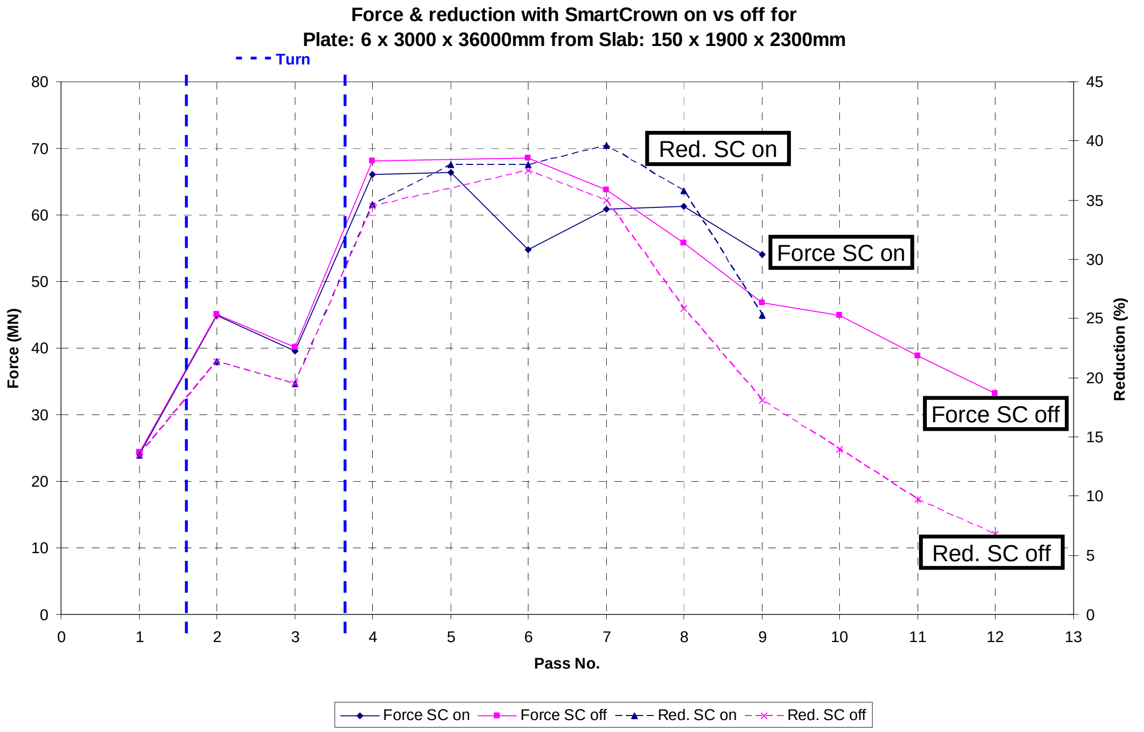


Figure 5. Comparison of rolling schedules with and without SmartCrown for a 6 mm x 3.000 mm x 36.000 mm plate with a 60µm target crown.

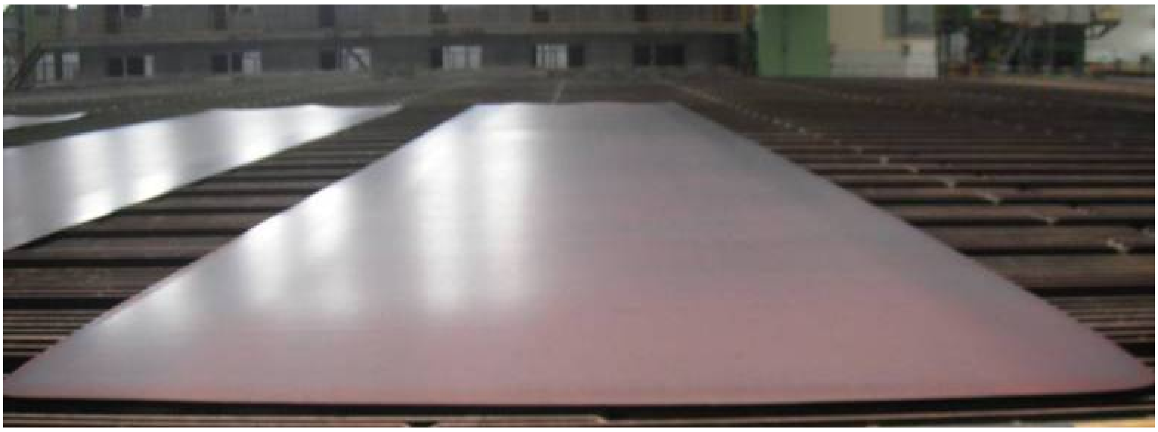


Figure 6. Photo of 6 mm x 3.100 mm x 27.000 mm plate after hot levelling on cooling bed.

The benefit also clear on TMCP plate. Figure 7 shows a comparison rolling schedule with and with SmartCrown® active for a 15 mm x 4.000 mm X70 plate (dummy passes are not shown). It is held at 5 times the final thickness (75 mm) until it has cooled to 880°C. There are some minor differences early in the schedule, but the significant difference is after the hold where the rolling loads are much higher. With SmartCrown® active it is possible to finish the plate in 5 passes compared to 7. This is because it is possible to change the roll gap profile to achieve the target crown of 100 µm. Effectively the tight TMCP process window is opened as there is now scope to use higher hold ratios to allow the development of even higher strength and toughness.

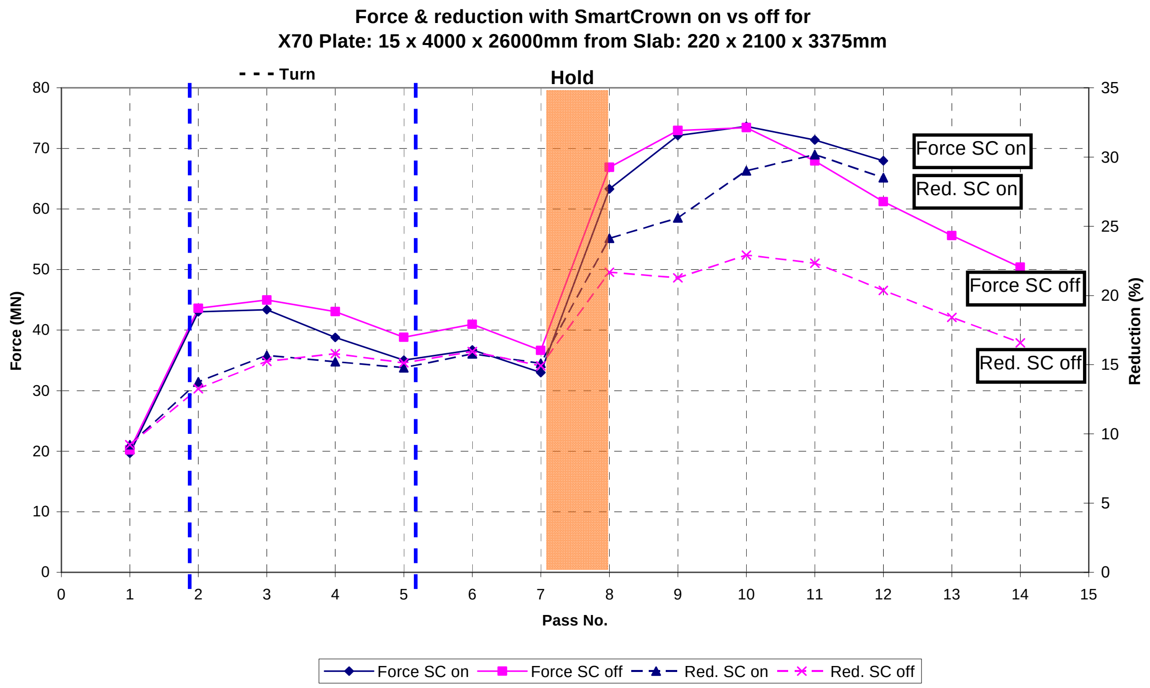
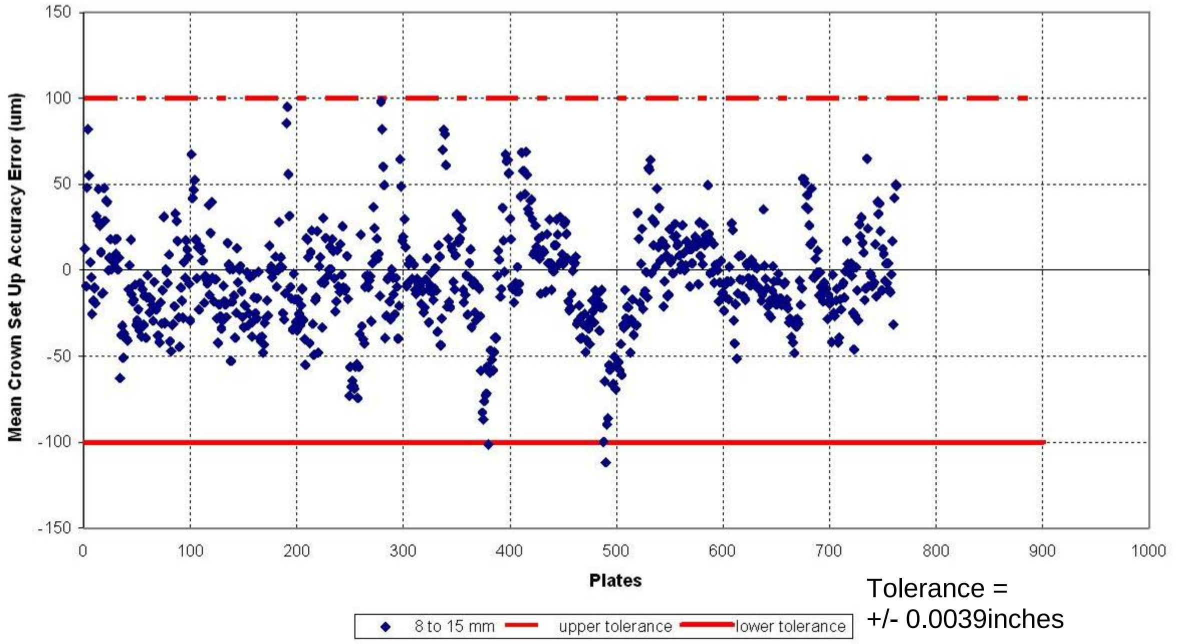


Figure 7. Comparison of rolling schedules with and without SmartCrown for a 14 mm x 4.000 mm x 26.000 mm plate with a 100 μm target crown.

A high degree of accuracy is possible in achieving the final plate crown. Figure 6 shows the crown error (measured – target) for a 8 mm to 15 mm thick plates for a 7 day period from a 4.3 m wide plate mill. It should be noted that this includes every plate in the thickness range rolled, even plates rolled at an unsuitable time in the rolling schedule (on worn rolls with significant width change). With correct production scheduling even better results are possible. Associated with this level of high performance is the ability to push production standards for the overall thickness tolerance on plate products, allowing yield improvements to be made and thickness closer to the minimum requirement can be targeted.



Tolerance =
+/- 0.0039inches

Figure 8. Crown error (microns, measured – target) for 8 mm-15 mm thick plates.

3 MULTI-POINT SETUP

3.1 Basic Description

The process automation (Level 2, L2) calculates a set of values like gap, force, bending force etc. in order to achieve a certain thickness. Additionally the setup contains sensitivities to enable the Level 1 (L1) automation system to compensate thickness differences due to force deviations, deviations in bending force etc. If this setup is calculated once per plate or strip it is called single point setup. A single point setup does not allow to roll material with thickness variations along the length. Changes in roll force along the rolled length can not be considered as well, and have to be compensated by automatic gauge control (AGC) or dynamic profile control (DPC).
The Solution for this problem is called Multi Point Setup (MPS). The setup values are calculated as a function of the rolled length. The setup vectors are loaded into the L1 system before the pass starts. L1 then follows the rolled length and calculates the needed setpoint by interpolation. This basic description is illustrate in Figure 9.

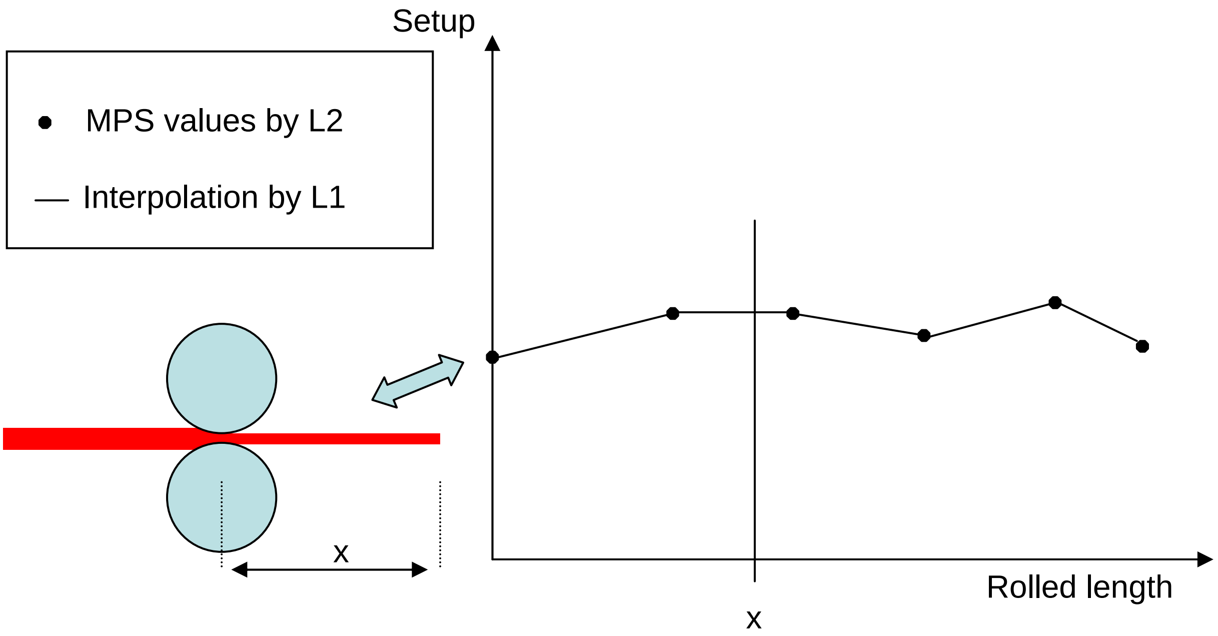


Figure 9. Diagram showing basic principal of a multi-point setup.

There are many benefits to having a multi-point rather than single point set-up:

- accurate setpoint already for 1st point at extreme head end, so technological controls (e.g. automatic gauge control) can be switched on earlier on the head end;
- very smooth start of controls with metal-in result in higher stability of rolling;
- pass schedule can go very close to mill limits with less risk i.e. more of the theoretical torque and rolling load can be used;
- tolerance band for thickness accuracy can be extended further towards the head and tail ends.

Additional there is the greater flexibility to produce complex thickness profiles, a summary of the different requirements are shown in Figure 10 where PVPC is plan view pattern control carried out in the sizing and broadsiding phases of rolling to produce a rectangular shaped plate, maximising yield. Longitudinally profiled (LP) plates, also know as taper plates can be produced with much greater accuracy, as there are multiple references to compare predicted loads, torques etc to.

Taper plates are used to save weight in several applications like shipbuilding. In the hull of the ship where greater thicknesses are needed closer to the keel. They are also used in bridges where the load requirements vary across the span. However, the amount of LP plate produced in the world annually is very small.

The longitudinal profile is created by controlling the rolling speed and hydraulic gauge control cylinder extension. This is only possible with good material tracking, speed control of the drives and the hydraulic gauge control cylinders.

The following section hopes to demonstrate the flexibility and accuracy that is possible with a multi-point setup and encourage the increased use of LP plates.

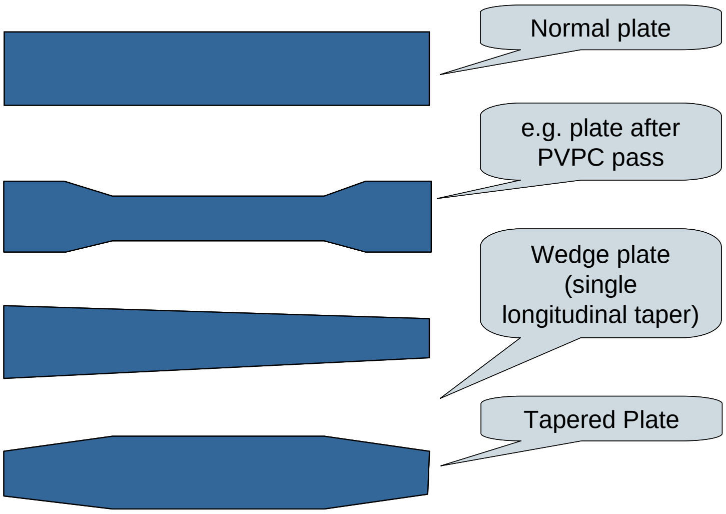


Figure 10. Uses of multi-point setup.

3.2 Recent Developments & Performance

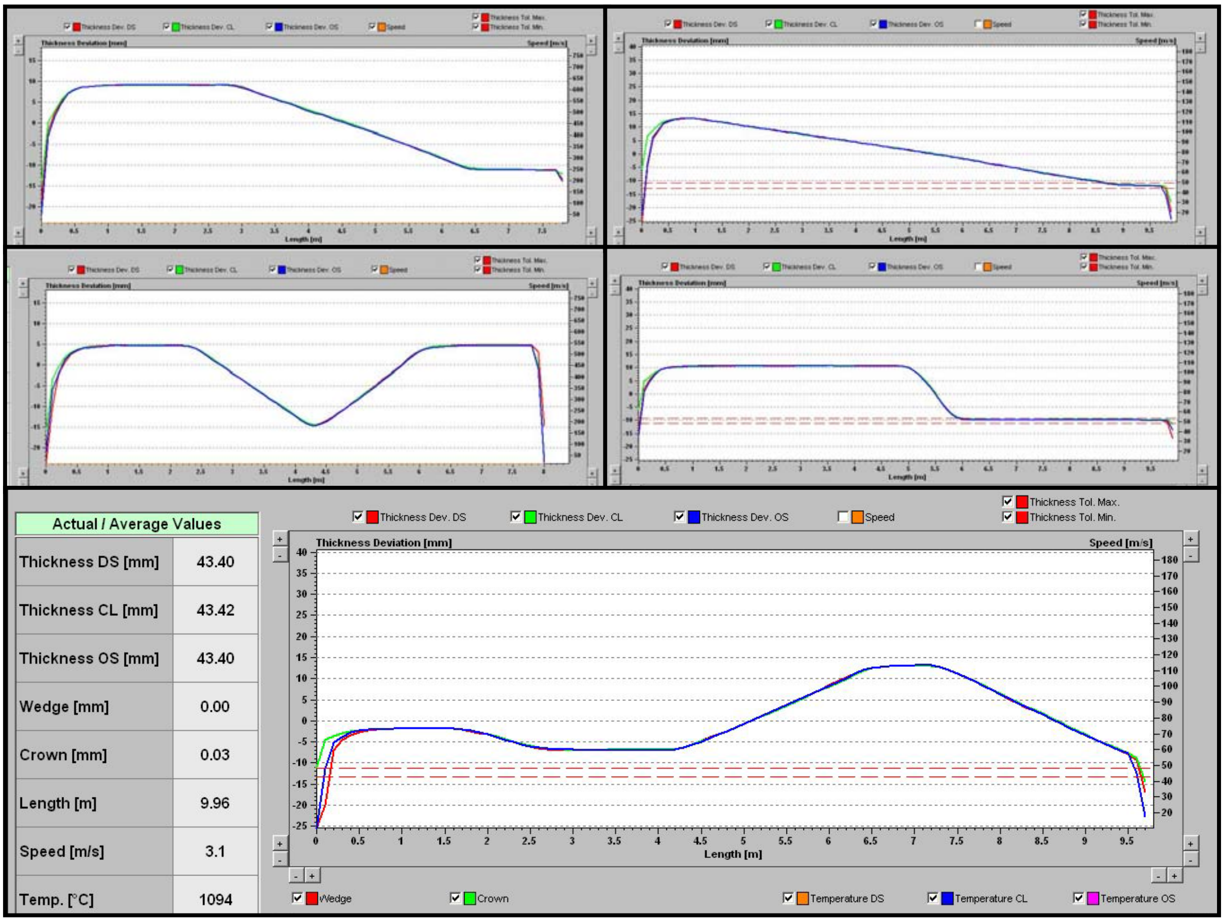
Multi-point setups using 7 points have been available from Siemens for several years and have demonstrated improved performance. With increased computing power it is possible to extend this even further. Trails with 20 points have been carried on producing plates with SIROLL automations systems on a 5 m wide plate mill. An example of this is shown in Figure 11.

Figure 11. 20 point setup showing predicted (blue), measured (red) rolling load & error (green).

The final 3 passes of a rolling schedule are shown and the detail of the final pass expanded. The red line is the measured rolling load and the blue the 20 point setup, the reference being interpolated between each point by the level 1 automation. The green line shows the error, which is small in the head (~15%) and is with +/- 5% in the plate body.

This is a very high degree of accuracy and should, with a confident mill operator, allow the use of scheduling limits on force and torques closer to the design limits of the equipment. This would have the obvious benefit of increasing productivity and allow larger drafts in the torque and load limited parts of the schedule, increasing strain penetration and improving impact properties.(8)

The implementation of multi-points setup automation on several plants allowed experimentation with the possible profiles for LP plates. Figure 12 shows 5 example profiles that were rolled on a 4.3 m wide plate mill, displaying screen shots of the thickness and profile gauge human machine interface (HMI).



Actual / Average Values	
Thickness DS [mm]	43.40
Thickness CL [mm]	43.42
Thickness OS [mm]	43.40
Wedge [mm]	0.00
Crown [mm]	0.03
Length [m]	9.96
Speed [m/s]	3.1
Temp. [°C]	1094

Figure 12. Thickness gauge measurements of 5 different LP plate examples.

The single taper or 'wedge' described earlier is shown in the top right of the figure. It can be seen that much more dramatic shapes can be made, with a high degree of accuracy. This was carried out using a 7 point setup. So there could be even more possibilities available in the future. The challenge now is for mechanical design engineers to come up with weight saving applications for LP plates.

4 CONCLUSIONS

- Increasing the available SmartCrown® range has allowed more aggressive rolling schedules to be used, increasing throughput further and allows more difficult products to be rolled;
- more extreme TMCP process windows can be achieved with the high loads possible in the finishing passes through the use of SmartCrown®;
- improved plate crown accuracy has been achieved allowing increases in yield by pushing production standards closer to the limit;
- rolling schedules can be pushed to the limit with the accuracy that multi-point setups provide, raising the possibility of further throughput and material property improvements;
- complex longitudinally profiled pates are possible to produce with the correct equipment and control. The challenge is finding weight saving engineering applications for them.

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